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ANALYSES OF LONG LIVED SLEPTON NLSP IN GMSB MODEL AT LINEAR COLLIDER [a]

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We performed an analysis on the detection of a long lived stau at a linear collider with $\sqrt{s} = 500$ GeV. In GMSB models a long lived NLSP is predicted for large value of the supersymmetry breaking scale F. Furthermore in a large portion of the parameter space this particle is a stau. Such heavy charged particles will leave a track in the tracking volume and hit the muon detector. In order to disentangle this signal from the muon background we explore kinematics and particle identification tools: time of flight device, dE/dX and Cerenkov devices.

In models where a gauge mediated sector is responsible for communicating Supersymmetry breaking to the MSSM sector [1,2] the gravitino is the lightest supersymmetric particle. Moreover, because of the very weak interaction of the gravitino, all supersymmetric particles will decay into the next lightest supersymmetric particle (NLSP). The life time of the NLSP can vary from an instantaneous decay to a decay outside the detector, depending on the value of the Supersymmetry breaking scale, F, which should be considered as a free parameter. Moreover, because soft terms in gauge mediated models are generated by gauge couplings, the NLSP is either a neutralino or a stau. In this workshop, the case for a neutralino NLSP, both long and short lived, was considered by Ambrosanio [3,4], and the case for a stau NLSP with prompt decay was considered by Kanaya [3]. In this analysis, we studied the search techniques for a stau NLSP in the production channel $e^+e^- \to \tilde{\tau}^+\tilde{\tau}^-$, in the context of a linear collider at $\sqrt{s} = 500$ GeV. The simulation package ISAJET [5] was used to perform our calculations.

The stau pair production at a linear collider provides a clean search enviroment. Futhermore, the production cross section is largely model-independent, depending only on the mass of the staus and on the mixing angle between the left and right superpartners. In Fig. 1a we show the pair production cross section (normalized to $\sigma_{\mu\mu} = 450$ fb) for the left and right states as a function of stau mass. We can see that the stau pair cross section is smaller than $\sigma_{\mu\mu}$, due to its scalar nature, and this cross section rapidly drops when we approach the kinematical limits of the accelerator. Nevertheless we note that for masses around 240 GeV we still have cross section of order of 10′s fb, which should be observable provided that the background is manageable.

The signal we are looking for are two back to back tracks with corresponding hits in the muon chamber. With this requirement tracks from π, K, p, e are removed. To reject the two photon process of $\gamma\gamma \to \mu^+\mu^-$, we note that the $\mu^+\mu^-$ pair in this process tends to have a low invariant mass and be boosted along the beam pipe. Thus, we require the following cuts:

[a] Talk given at the four International Workshop on Linear Colliders (LCWS99), April 28 - May 5, Sitges, Barcelona, Spain.

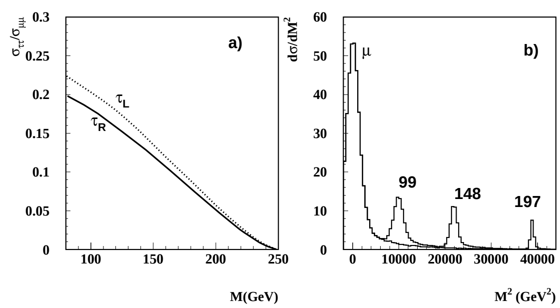

Figure 1: a) Stau pair cross section as a function of mass, for a right and left stau state, normalized by the muon pair cross section. b) $d\sigma/dM$ for several values of stau masses. Also shown is the μ background. The width of the peaks reflect the uncertainty in the momentum measurement.

1. $\cos\theta < 0.8$, to guarantee good track quality;
2. $|P| > 0.5E_{\rm beam}$ and
3. $|(P_{\rm tot})_z| < 0.25E_{\rm beam}$.

After these cuts, the two photon muon pair production is estimated to be 1.4 fb. We are then left with muon pair production $e^+e^- \to \mu^+\mu^-$ as the main source of backgrounds.

In order to reduce the muon pair background we shall explore the heavy mass of the staus. In a e^+e^- collider the energy in the center of mass is fixed, so in a pair production process the energy of the final particles is also known. It is well known, however, that in a high energy linear collider beamstraulung and initial state radiation effects become important and the effective energy of the reaction is not fixed but presents a spectrum. Nevertheless it is well aproximated by one photon emission from one of the initial state $e^\pm$. With this aproximation, the mass estimate for each track is given by:

$$M^2 = \left(\frac{\sqrt{\hat{s}}}{2\gamma} + \beta p_z\right)^2 - |p|^2 \,, \tag{1}$$

$$\hat{s} = s(1-|\Delta|) \,, \tag{2}$$

$$\beta = \Delta/(2-|\Delta|) \,, \tag{3}$$

where $\Delta = p_z^{\rm tot}/E_{\rm beam}$ is the net momentum in the beam line direction, β is the boost parameter and $\sqrt{\hat{s}}$ is the center of mass energy of the two tracks.

In Fig. 1b is shown the cross section distribution as a function of M^2 which is estimated according to (1). In this plot we can see the muon distribution peaking at zero mass with a tail from beamstraulung. We also see the distribution of staus production for several values of masses. The momentum resolution is taken to be $\delta P_t/P_t = 5X10^{-5}P_t$ (GeV). Based in this plot we use the following cut,

4. $|M^2 - M_{\tilde{\tau}}^2| < 3000\ \ \mathrm{GeV}^2$;

Where $M_{\tilde{\tau}}$ is a variable parameter in the search. The resulting efficiency after this cut is shown as the dotted line of Fig 2a.

To futher improve the sensitivity, we study particle identification. A time of flight device can be used to identify heavy tracks. In our study we considered a linear collider with 1.4 ns of bunch separation. In the large detector scenario ($r = 2$m) the mean time of flight for a massless ($\beta = 1$) particle is around 6.7 ns. We assumed that we do not know which bunch crossing a given event is coming from and simulated the effect of a 50 ps error in the time of flight measurement. We apply the following cut,

5. $\Delta t > 0.13$ ns, where Δt is the time of flight difference between a $\beta = 1$ and a massive particle, modulo 1.4 ns.

This cut correspond to about 2.5σ, so that about 1% of the muon background are kept. Applying this cut to both tracks we can relax cuts 2 and 3 which extends the mass range to the full beam energy. The efficiency of this cut as a function of mass is shown in Fig. 2a as the solid line.

When a charged particle goes through the detector it deposit energy by ionization. The amount of energy deposit, dE/dX, is a function of $\beta\gamma$ of the particle[6]. For a heigh momentum muon going through Argonne we expected $dE/dX \sim$ 2.63(MeV $\mathrm{g}^{-1}\mathrm{cm}^2$). Based on 5% resolution for dE/dX, which is a realistic value for a large TPC, we propose the following cut,

6. $|dE/dX - 2.63| < 0.4$; where the units are (MeV $\mathrm{g}^{-1}\mathrm{cm}^2$).

The resulting efficiency is shown as the dashed line of Fig. 2a. We note a blind spot for masses around 150 GeV.

In Fig. 2b we present, for each strategy, the minimum cross section that will be visible at a $\sqrt{s} = 500$ GeV linear collider with 50 fb^{-1}. Our criteria is based on a 3 sigma significance; namely, $S \geq 3$ with $S = \epsilon\sigma\sqrt{L/bg}$, where σ is the signal cross section, ϵ is the efficiency to pass the cuts and bg is the expected background cross section after cuts. We require a minimum of 5 signal events after cuts.

A Cerenkov device can be used to measure $\beta\gamma$. With a device similar to the Babar detector it is possible to reject particles with $\beta\gamma > 8$. We considered the case of 4.5% rejection factor for the light particle (muons) while keeping nearly 100% of the heavy particles. With this estimative the efficiency of the strategy is the same as using just the kinematical cuts. The minimum signal cross section, however, will

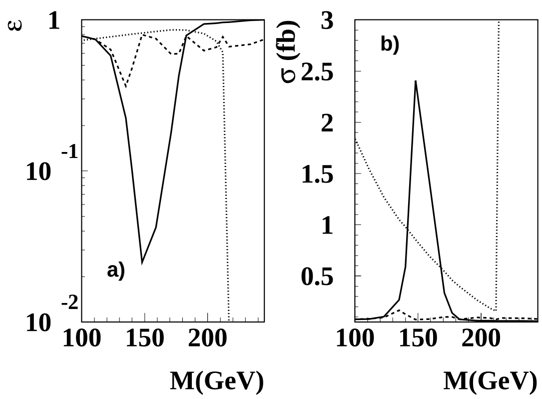

Figure 2: a) The efficiency for the signal to pass the various cuts. The dotted line stands for cuts 1-4, the dashed line for cuts 1 and 5 and the solid lines for cuts 1 and 6. b) Minimum signal cross section to be observed in a 3 S effect for each set of cuts, same convention as in a).

be given by the 5 event requirement and the reach will extend all the way to the full beam energy.

A comment on the nature of our results is in order. We have presented a strategy based only on the pair production mechanism where particle identification had a relatively minor role to play. Nevertheless, in the models under consideration it is likely that others supersymmetric particles will be produced and end up in stau; in such decay chains the use of time of flight, dE/dX and Cerenkov devices would play a critical role in identifying staus [b].

Up to this point we supposed a stau that mostly do not decay within the detector; however, as mentioned earlier, the life time can be viewed as a free parameter of the model. We will now discuss a simple measurement of the stau life time using the mode $e^+e^- \to \tilde{\tau}^+\tilde{\tau}^-$. The case of a short lived stau is to be studied elsewhere.

In Fig. 3 we present contours for the number of stau that decay between radii 1m and 2m for the integrated luminosity of 50 fb^{-1} plotted as a function of stau mass and life time. In order to ensure good measurement of momentum and dE/dX we require that each event should have two tracks longer than 1 meter, using just the mass cut 4 to select the events. We believe that such events will be essentially background free: two well reconstructed back to back tracks, consistent kinematically with a heavy particle and with at least one of the tracks presenting a kink or fork from the decay $\tilde{\tau} \to \tau\tilde{G}$. The figure indicates that there is a two fold ambiguity

[b] The kinematical distribution, as proposed here, would be of no use in a process other than pair production.

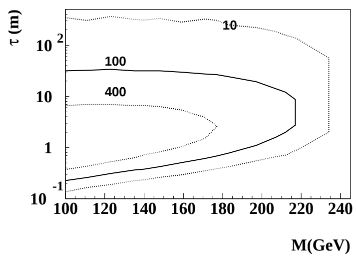

Figure 3: Contours of number of tracks decaying between 1m and 2m.

for the life time: for example, for $M = 140$ GeV and 100 decay events in $1 < r < 2$ m the measured life time is $c\tau = 31 \pm 3$m or $c\tau = 0.38 \pm 0.04$m. This ambiguity, however, is easily resolved by a full fit of the decay distribution.

In summary, we have studied the long lived stau pair production in a linear collider at $\sqrt{s} = 500$ GeV. Due to the clean kinematics and the well predicted production cross section, measurement of momentum alone can detect such particle with masses up to 85% of the beam energy. Particle identification devices extend the mass range to essentially the full beam energy. We have also performed a preliminary study of lifetime measurement.

Acknowledgments

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